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AN ALGORITHM FOR CORRECTION OF LUNAR CONTAMINATION IN AMSU-A DATA

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AN ALGORITHM FOR CORRECTION OF LUNAR CONTAMINATION IN AMSU-A DATA

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An Algorithm for Correction of Lunar Contamination in AMSU-A Data

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Abstract

An algorithm is developed for detection and correction of the lunar contamination observed in the Advanced Microwave Sounding Unit (AMSU-A) data. Occurrence of the lunar contamination has been observed several times per year with an irregular period. Over each orbit of data, about 200 scans may be contaminated during the lunar contamination occurrence that may last as long as 24 hours and the closest time interval between two occurrences is 28 days. The algorithm is modeled using the lunar position and phase. Combined with the measured AMSU-A antenna pattern, the algorithm executes a line-by-line detection and correction of the lunar contamination induced in the AMSU-A cold space radiometric counts when the Moon moves across the AMSU-A cold calibration field of views. The model can accurately detect and remove most of the lunar contamination from the cold space counts. Test results show that more than 90% of the lunar contamination can be eliminated from the AMSU-A cold space counts. A set of computer software is under development to incorporate this algorithm into the NESDIS operational preprocessor for improving the AMSU-A calibration accuracy.

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1. Introduction

The Advanced Microwave Sounding Unit-A (AMSU-A) is a new generation of total-power microwave radiometers built for the NOAA-K, L, M, N, and N' series of Polar-orbiting Operational Environmental Satellites (POES). Traditionally, an NOAA spacecraft is named by an alphabetical letter before launch after which, a numerical series number replaces its letter nomenclature. The AMSU-A radiometers onboard NOAA-15, -16, and –17, which were launched in May 1998, September 2000, and June 2002, respectively, are the first three of the series. Each AMSU-A instrument is composed of two separate units: AMSU-A2 with channels 1 and 2 at 23.8 and 31.4 GHz, and AMSU-A1 with twelve channels in the range of 50.3 to 57.3 GHz which are used for temperature sounding from the surface to about 50 km, (i.e., from ~1000 to ~1 mb) plus channel 15 at 89.0 GHz. Channel 3 at 50.3 GHz is also a window channel, as it senses atmospheric temperatures near the surface. In total, AMSU-A furnishes 15 channels. A more complete description of the AMSU-A instrument and its radiometric performance was reported elsewhere [1]. The main channel characteristics of the NOAA-16 AMSU-A instruments can be found in [2]. Channels 1-3 and 15, collectively referred to as the window channels, aid the retrieval of temperature soundings by providing information to correct the effects due to surface emissivity, atmospheric liquid water, and total precipitable water vapor. The two low frequency channels also provide information on precipitation, sea ice, and snow cover.

AMSU-A is a cross-track, step-scan instrument and executes one complete revolution every 8-second period. The AMSU-A antenna systems have a nominal field-of-view (FOV) of $3^{o}20'$ at the half-power points (covering a 50-km diameter footprint at nadir) and execute a cross-track scan with 30 Earth FOVs (within $\pm 48^{o}20'$ from the nadir direction), one cold calibration FOV, and one warm blackbody FOV per 8-second scan period. Beam positions 1 and 30 are the outermost scan positions of the Earth views, while beam positions 15 and 16 (at $\pm 1.67^{o}$from nadir) straddle the nadir.

AMSU-A is a self-calibrating total power radiometer. The on-board calibration is achieved by viewing a scene of cold space and an internal blackbody target. This provides a two-point calibration references.[2] AMSU-A has four possible space view (SV) positions, which are referred to as SV1, SV2, SV3, and SV4, located at 83.3°, 81.67°, 80.0°, and 76.67°, respectively, from the Nadir. SV1 is closest to the spacecraft platform and therefore possibly susceptible to contamination from the spacecraft. SV4 is closest to the Nadir therefore possibly susceptible to contamination from the Earth and atmosphere. One of the space views must be chosen in the normal on-orbit operation. An optimally chosen space view position will produce space radiometric counts with minimum contamination from all sources (including the spacecraft, atmosphere, and the Earth). In current NESDIS operation, AMSU-A1 use SV1 and AMSU-A2 uses SV2 (except NOAA-15 AMSU-A2 also uses SV1).

Lunar contamination of the space radiometric counts occurs whenever the Moon moves across the space FOV. It has been observed that this happens several times a year. A full Moon disk subtends an approximate 0.5° cone angle at POES and the AMSU-A antenna 3-dB beam widths are 3.33°. Thus, a maximum of 2% [$\cong (0.5/3.33)^2$] of Moonlight may get into the AMSU-A cold space counts. The contaminated cold space counts C_c' can be estimated by the relation, $C_c' = (1-\beta)C_c + \beta C_m$, where $\beta \leq 0.02$ is the ratio of the Moon disk to the area within the 3-dB antenna-beam cone as defined above. The C_m represents the radiometric count corresponding to the lunar surface brightness temperature which can vary from 120 to 380 K while the C_c is the radiometric count of the deep space cosmic background temperature T_C=2.73 K.

It has been observed that a maximum of 40 extra counts (due to lunar contamination) above the nominal values appeared in the AMSU-A space counts. This is not easy for the current preprocessor to detect, since it is comparable with the normal orbital variation. In the worst case, it is estimated that this 40 extra cold counts can produce an error of ~1.2K in the measured ocean brightness temperature of 150K at Channel 1. As the scene temperature increases, the error decreases (vanishes at the warm blackbody calibration temperature). The AMSU-A data have been used extensively in many applications [3-5] at NOAA and worldwide agencies to generate products for weather forecasting, atmospheric temperature

[2] There is also a small nonlinear contribution, which is of the order of 1K or less, cannot be evaluated by the two-point in-orbit calibration and must be determined from the pre-launch calibration data.

sounding, and hydrological studies. An error of ~1.2K could have significant adverse effect on the above products. Since enough observation of the lunar contamination has been accumulated, it is desired to develop a reliable and efficient algorithm to detect and eliminate these lunar contaminations from the cold space counts. This study was undertaken to develop such an algorithm for correcting the adverse effect of lunar contamination on the retrieved products.

2. Lunar Contamination of AMSU-A Space Counts

The scan geometry of the AMSU-A is shown in Figure 1. The AMSU-A takes one sample at each of 30 Earth FOVs per scan by a stepped-scan fashion. Calibration information is obtained by acquiring two samples each when the AMSU-A antenna looks at the cold space (cold calibration) and the internal blackbody (blackbody calibration).

Figure 2 shows the one-day track of the Moon relative to NOAA-16 on May 31, 2001. The horizontal and vertical axes of Figure 2 are the azimuth and elevation angles in the local coordinates that are defined by the cold calibration position (both azimuth and elevation are zeroes) and orbital velocity (azimuth is –90 degrees, and elevation is 0). From the top of the satellite, one can track the Moon like Figure 2. As mentioned above, the NOAA-16 AMSU-A1 and A2 use two different cold calibration positions, therefore two circles in Figure 2 are shown for the FOVs of A1 and A2, respectively, when the Moon moves across these FOVs once per orbit with maximum illumination to the cold space FOVs.

Figure 3 shows the one-day cold space radiometric counts (bottom part) and the corresponding separation angles (top part) between the Moon and cold calibration position at the same date as Figure 2. In the bottom part of Figure 3, the broad peaks are the nominal cold space radiometric counts from individual orbits whereas the narrow peaks are the lunar contaminations. From Figure 3, one can see that the Moon can contaminate the cold space radiometric counts whenever the Moon-SV separation angle is less than 4^{o} beyond which, the AMSU-A antenna power drops below 40-dB. One of the lunar contamination peaks is indicated between the two vertical dashed-lines. The maximum contamination at the peak location is about 40 counts.

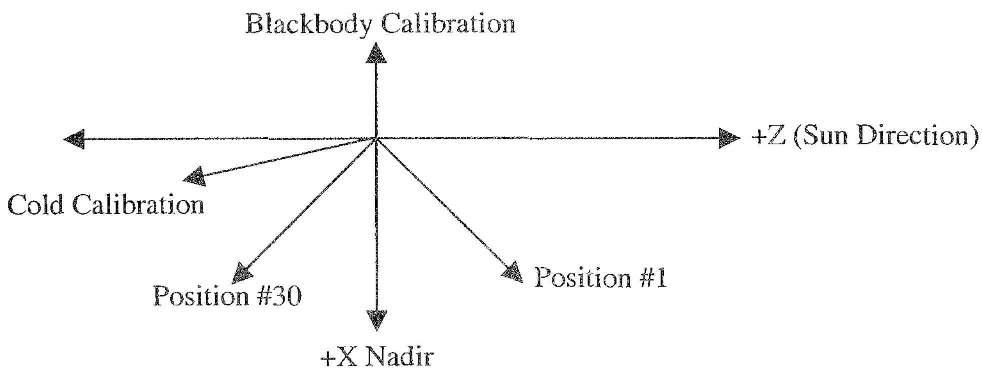

Figure 1. Conceptual Scan Geometry of AMSU-A

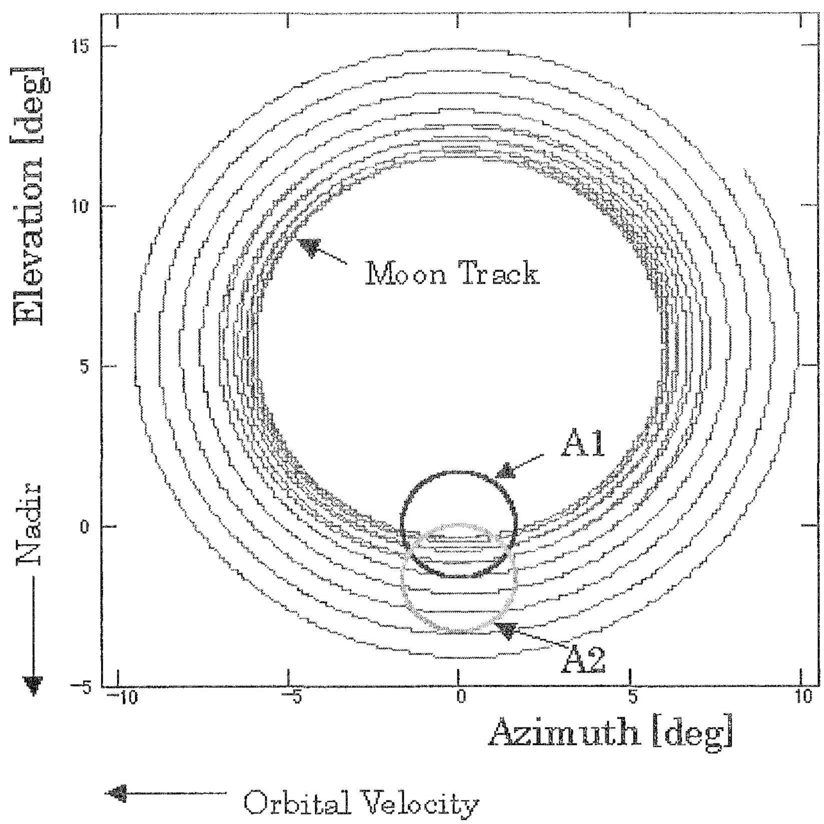

Figure 2. One-Day Track of Moon

The circles A1 and A2 represent the FOVs of AMSU-A1 and –A2, respectively. The track is the view of NOAA-16 on May 31, 2001.

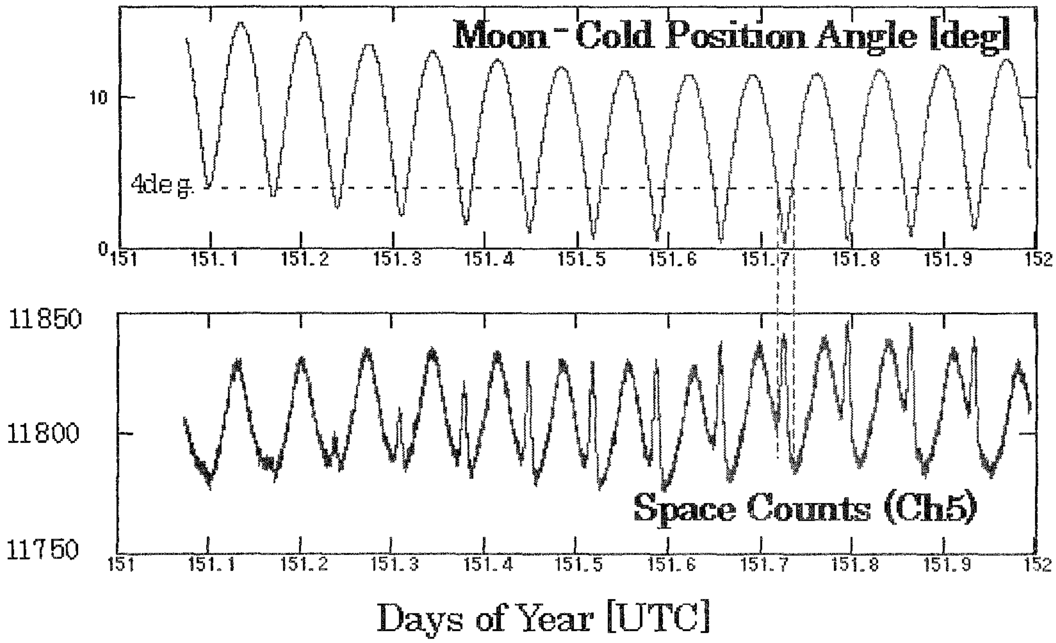

Figure 3. One-Day Space Counts and Moon-Cold Calibration Separation Angle NOAA-16 on May 31, 2001

3. Equations for Correction of Lunar Contamination

The corrected value of the cold space radiometric counts is calculated by the following equations.

$$\left.\begin{aligned} C_c' &= \frac{(T_w - T_c)\cdot C_c - \Delta T_c \cdot C_w}{T_w - T_c - \Delta T_c} \\ \Delta T_c &= \exp\left(-\frac{(\alpha-\alpha_0)^2}{2\alpha_s{}^2}\right)\exp\left(-\frac{(\delta-\delta_0)^2}{2\delta_s{}^2}\right)\cdot\beta\cdot T_{moon}\cdot\left(\frac{60.3\times 6378}{d}\right)^2 \end{aligned}\right\} \quad (1)$$

Where C_c': corrected space counts [counts], with lunar contamination removed

C_c: observed space counts [counts], including lunar contamination

C_w: observed blackbody counts [counts]

T_c: space background temperature [K]

T_w: blackbody temperature [K]

α: lunar azimuth [degrees]

α_0: FOV center azimuth [degrees] (See Table 1 and 2)

α_s: FOV azimuth size factor [degrees] (See Table 1 and 2)

δ: lunar elevation [degrees]

δ_0: FOV center elevation [degrees] (See Table 1 and 2)

δ_s: FOV elevation size factor [degrees] (See Table 1 and 2)

β: nominal area ratio of moon to FOV (See Table 1 and 2)

d: distance between satellite and moon [km]

T_{moon}: effective moon temperature [K]

$= 95.21 + 104.63(1-\cos\theta) + 11.62(1+\cos 2\theta)$

θ: separation angle between moon and sun

Tables 1 and 2 show five constant parameters (α_s, α_0, δ_s, δ_0, and β). Table 1 is based on pre-launch high-resolution measurements of the antenna patterns on the ground, while Table 2 is generated by the on-orbit measurement that will be described later.

Channel	NOAA-15					NOAA-16				
	α_s	α_0	δ_s	δ_0	β	α_s	α_0	δ_s	δ_0	β
1	1.501	-0.153	1.508	-0.124	0.01484	1.487	-0.048	1.518	-0.098	0.01489
2	1.447	-0.127	1.456	-0.095	0.01594	1.445	-0.069	1.485	-0.075	0.01565
3	1.595	0.138	1.599	0.062	0.01320	1.529	-0.027	1.546	-0.012	0.01422
4	1.593	0.127	1.572	-0.010	0.01344	1.508	-0.013	1.525	-0.014	0.01461
5	1.542	0.082	1.568	-0.009	0.01391	1.497	0.000	1.510	0.008	0.01486
6	1.527	-0.015	1.579	0.098	0.01395	1.476	0.153	1.491	-0.055	0.01526
7	1.572	0.008	1.516	0.060	0.01411	1.466	0.114	1.488	-0.132	0.01540
8	1.578	0.026	1.528	-0.080	0.01398	1.520	-0.009	1.512	0.014	0.01462
9	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
10	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
11	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
12	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
13	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
14	1.578	-0.003	1.521	0.077	0.01401	1.426	0.127	1.432	-0.096	0.01644
15	1.802	-0.002	1.557	0.051	0.01204	1.401	0.090	1.342	-0.078	0.01785
Unit	Deg.	Deg.	Deg.	Deg.	-	Deg.	Deg.	Deg.	Deg.	-

Table 1. Constant Coefficients based on Pre-launch Measurement.

Channel	NOAA-15					NOAA-16				
	α_s	α_0	δ_s	δ_0	β	α_s	α_0	δ_s	δ_0	β
1	1.501	-0.200	1.508	-0.124	0.01484	1.500	0.150	1.518	-0.098	0.01476
2	1.447	-0.200	1.456	-0.095	0.01594	1.450	0.075	1.485	-0.075	0.01560
3	1.595	-0.150	1.599	0.062	0.01320	1.588	-0.100	1.546	-0.012	0.01370
4	1.593	-0.200	1.572	-0.010	0.01344	1.575	-0.050	1.525	-0.014	0.01400
5	1.542	-0.300	1.568	-0.009	0.01391	1.488	-0.075	1.510	0.008	0.01495
6	1.527	-0.300	1.579	0.098	0.01395	1.538	0.250	1.491	-0.100	0.01300
7	1.572	-0.300	1.516	0.060	0.01411	1.538	0.250	1.488	-0.100	0.01300
8	1.574	-0.200	1.528	-0.080	0.01398	1.563	-0.050	1.512	0.014	0.01423
9	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
10	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
11	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
12	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
13	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
14	1.578	-0.100	1.521	0.077	0.01401	1.538	0.200	1.432	-0.096	0.01200
15	1.802	-0.100	1.557	0.051	0.01204	1.538	0.200	1.342	-0.078	0.01200
Unit	Deg.	Deg.	Deg.	Deg.	-	Deg.	Deg.	Deg.	Deg.	-

Table 2. Constant Coefficients based on On-orbit Measurement.

3.1 Lunar Azimuth, Elevation and Distance

The following are descriptions for the lunar azimuth, elevation, distance, and effective moon temperature.

3.1.1 Satellite Position and Attitude

The position and attitude of the satellite can be calculated by the Earth location data in the AMSU-A Level 1B data sets. Description of the method of calculating the position and attitude has been given elsewhere [6].

3.1.2 Cold Calibration Pointing Vector

The pointing vector of the cold calibration position in the satellite coordinates is obtained by a cold calibration position angle, θ_{cc}, as defined by Equation (38) in [6] as follows,

$$\begin{pmatrix} x_{ccp} \\ y_{ccp} \\ z_{ccp} \end{pmatrix} = L \cdot \begin{pmatrix} \cos\theta_{cc} \\ 0 \\ \sin\theta_{cc} \end{pmatrix} \qquad (2)$$

where **L** is the attitude correction matrix as defined by Equation (37) in [6].

The pointing vector of the cold calibration position in the earth fixed coordinates is given by

$$\begin{pmatrix} x_{cc} \\ y_{cc} \\ z_{cc} \end{pmatrix} = \begin{pmatrix} x_{yaw} \\ y_{yaw} \\ z_{yaw} \end{pmatrix} \cdot x_{ccp} + \begin{pmatrix} x_{roll} \\ y_{roll} \\ z_{roll} \end{pmatrix} \cdot y_{ccp} + \begin{pmatrix} x_{pitch} \\ y_{pitch} \\ z_{pitch} \end{pmatrix} \cdot z_{ccp} \tag{3}$$

3.1.3 Moon and Sun Position

The details of calculating the position of the Moon and Sun are described by Keith Burnett[3], who shows that Moon position is within 4 arcminnutes of the apparent geocentric position. This reference was selected in consideration of position accuracy and simple software design. The sample software of the lunar contamination correction is given in Appendix A.

3.1.4 Azimuth and Elevation

The local coordinates are introduced to calculate the lunar azimuth and elevation used in Equation (1). The axes of the local coordinates are defined as the direction of the cold calibration position (axis 1), the direction of orbital velocity (axis 3), and their vector product (axis 2). The azimuth and elevation of the local coordinates are defined by the cold calibration position (both azimuth and elevation are zeroes) and orbital velocity (azimuth is –90 degrees, and elevation is 0). The conversion of the Moon pointing vector from the Earth fixed coordinates (x_{moon}, y_{moon}, z_{moon}) to the local coordinates (a_1, a_2, a_3) is obtained by solving the following equation.

$$\begin{pmatrix} x_{cc} & -y_{roll} \cdot z_{cc} + y_{cc} \cdot z_{roll} & -x_{roll} \\ y_{cc} & -z_{roll} \cdot x_{cc} + z_{cc} \cdot x_{roll} & -y_{roll} \\ z_{cc} & -x_{roll} \cdot y_{cc} + x_{cc} \cdot y_{roll} & -z_{roll} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} x_{moon} \\ y_{moon} \\ z_{moon} \end{pmatrix} \tag{4}$$

[3] http://www.btinternet.com/~kburnett/kepler/moon2.html

The azimuth, α, and elevation, δ, are given by

$$\left.\begin{aligned} \alpha &= -\tan^{-1}\left(a_3 / a_1 \right) \\ \delta &= -\tan^{-1}\left(a_2 \Big/ \sqrt{a_1^2 + a_3^2} \right) \end{aligned}\right\} \tag{5}$$

3.2 Effective Moon Temperature

The lunar surface temperatures of 380K by day and 120K by night are well known. The Moon has been used to monitor the radiometric stability of satellite-borne remote sensors [7, 8]. In this study, the lunar surface temperature is assumed as shown in Figure 4. The daytime temperature is expressed in proportion to the fourth root of the cosine of the solar zenith angle.

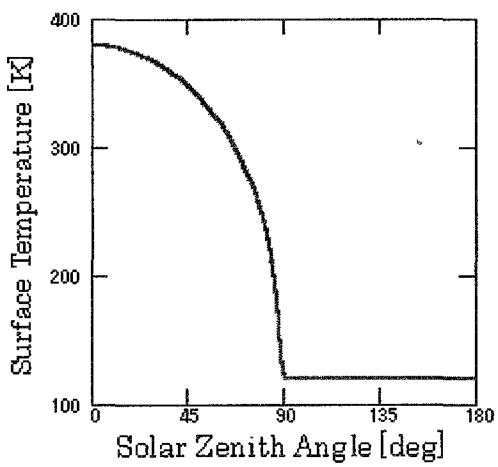

Figure 4. Model of Lunar Surface Temperature.

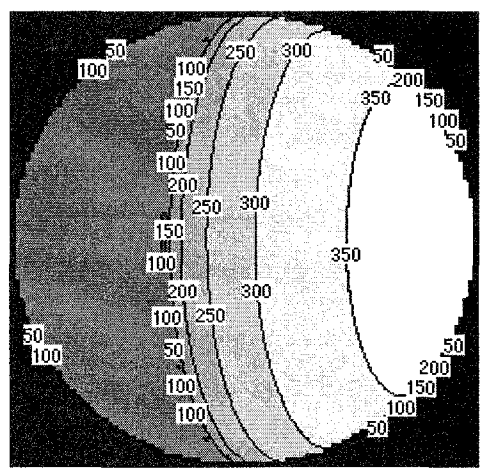

Figure 5. Example of Lunar Temperature Map in case of Moon-Sun Separation Angle of 110°. Unit is degree Kelvin.

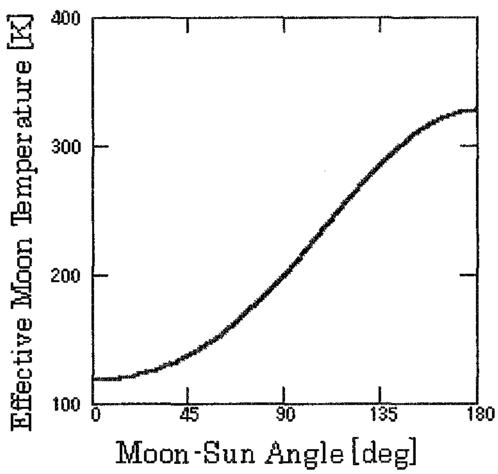

Figure 6. Effective Moon Temperature
Maximum Temperature appears in case of Full Moon (Moon-Sun Angle =180°.)

Figure 5 shows an example of the lunar surface temperature map based on the assumption shown in Figure 4. The effective Moon temperature is defined as the mean temperature of the full disk of the Moon. The effective Moon temperature, T_{moon}, is shown in Figure 6 as a function of a separation angle between the Moon and Sun, θ, and can be approximated by

$$T_{moon} = 95.21 + 104.63(1 - \cos\theta) + 11.62(1 + \cos 2\theta) \tag{6}$$

It is assumed that the surface emissivity of the Moon is 1 in Equation (1) since the apparent diameter is very small relative to the AMSU-A FOVs. On the Moon surface, there are many craters that produce a cavity effect.

4. Results

The formulas derived above are used to correct the lunar contaminations observed in the cold space radiometric counts of the NOAA-15 and –16 AMSU-A 1b data. Figure 7 through 12 show the observed and corrected space-view counts of NOAA-15 and –16 using Equation (1) and the antenna parameters given in Tables 1 and 2. Channels are shown according to the three AMSU-A antenna systems: A1-1 (Channels 6, 7, and 9-15), A1-2 (Channels 3-5, and 8), and A2 (Channels 1and 2). In these figures, the peaks labeled as "observed" (note: the labels are placed only on Channel 1, but peaks on other channels are the same) are caused by lunar contamination. The curves labeled as "corrected" indicate that the lunar contamination have been removed from the cold space counts.

There are some ripples appeared on the corrected curves when the pre-launch measurements of antenna coefficients are used. These ripples can be reduced if the antenna coefficients derived from the on-orbit measurements of antenna pattern are used. This is described in the next section as how to refine the antenna coefficients that remove the ripples.

5. On-orbit Antenna Pattern Measurement

The ripples that appear on the corrected cold space counts shown in Figures 7-12 can be interpreted as a consequence that there are differences between the pre-launch antenna pattern measurement and the actual on-orbit antenna pattern. Figure 13 shows the plots of the space counts as a function of time from one orbit of AMSU-A data. The lunar effect on the space counts can be seen in the upper left. The data that is expected to have the lunar effect is removed by referring the angle between the moon and cold calibration position (lower left). The remaining data that would have no lunar effect is interpolated (lower right). If the interpolated space counts agree with the true value of the space counts within an acceptable error, the lunar effect can be estimated by calculating the difference between the observed and interpolated space counts (upper right). Although the moon is not a point radiance source, the relative intensity of the lunar effect shows the on-orbit antenna pattern because the solid angle of the moon is smaller than the field-of-view of the AMSU-A, and the antenna pattern is approximated by a Gaussian curve. The results of the on-orbit antenna pattern measurement are shown in Table 2. This technique will help the post-launch checkout of future satellites.

6. Conclusion

An algorithm for detection and correction of the lunar contamination in the AMSU-A space counts was developed and applied to the NOAA-15 and –16 AMSU-A data. Test results show that the algorithm can accurately detect and eliminate the lunar contamination from the observed AMSU-A space counts. The results from this study are summarized as follows,

- Lunar effect on the space counts when the Moon moves across the AMSU-A cold calibration FOVs is modeled using the lunar position and phase.
- The model can accurately detect the lunar contamination and remove most of the lunar contamination from the space counts. Test results show that more than 90% of the lunar contamination can be eliminated from the AMSU-A space counts.
- The description of the algorithm provides a guide for further development of software for operational use.
- The algorithm also provides an outline to readjust the on-orbit antenna patterns.

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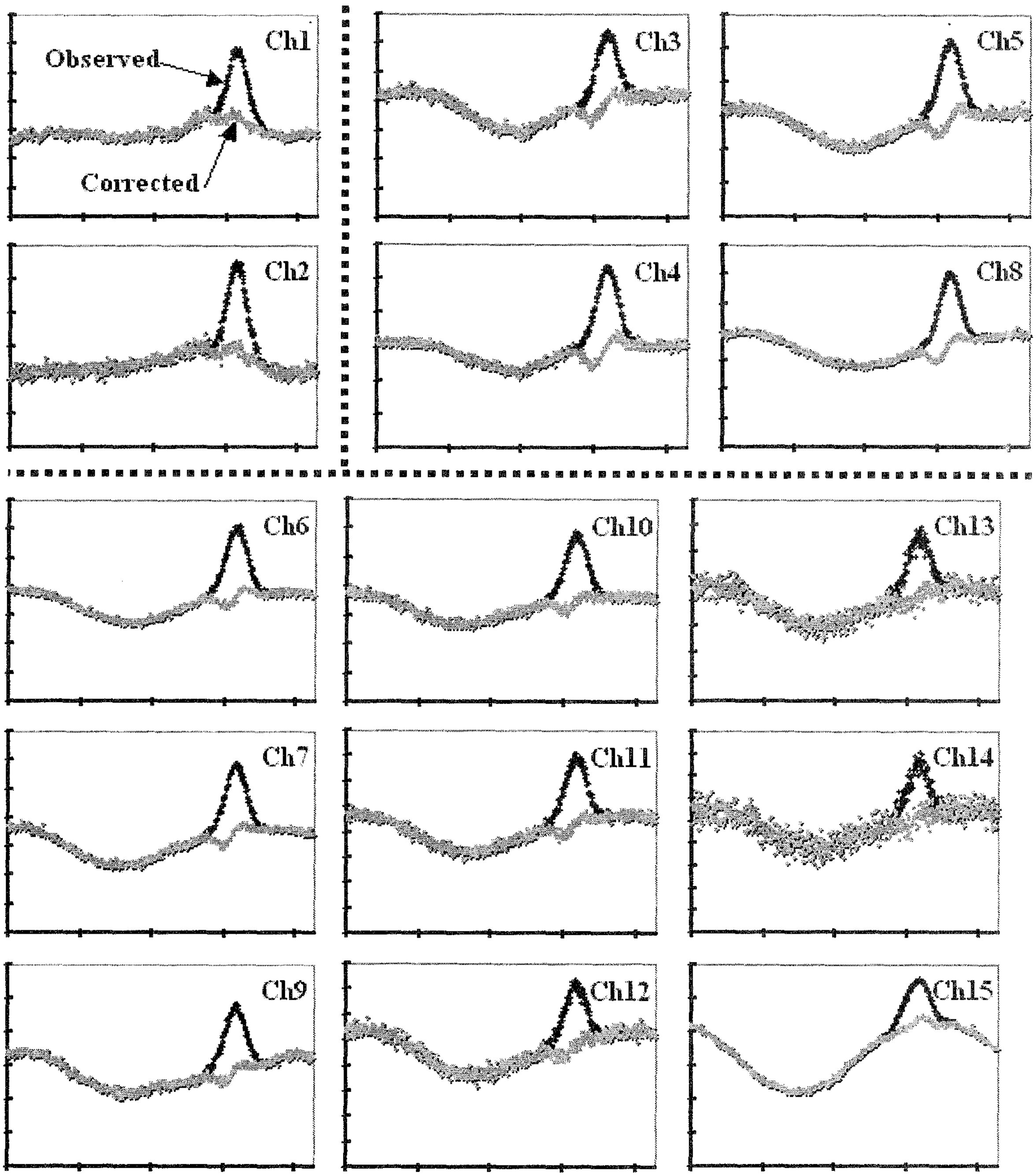

Figure 7. Space Counts Correction based on Pre-launch Antenna Pattern.
[NOAA-15, 2/21/2000, 1320-1514UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

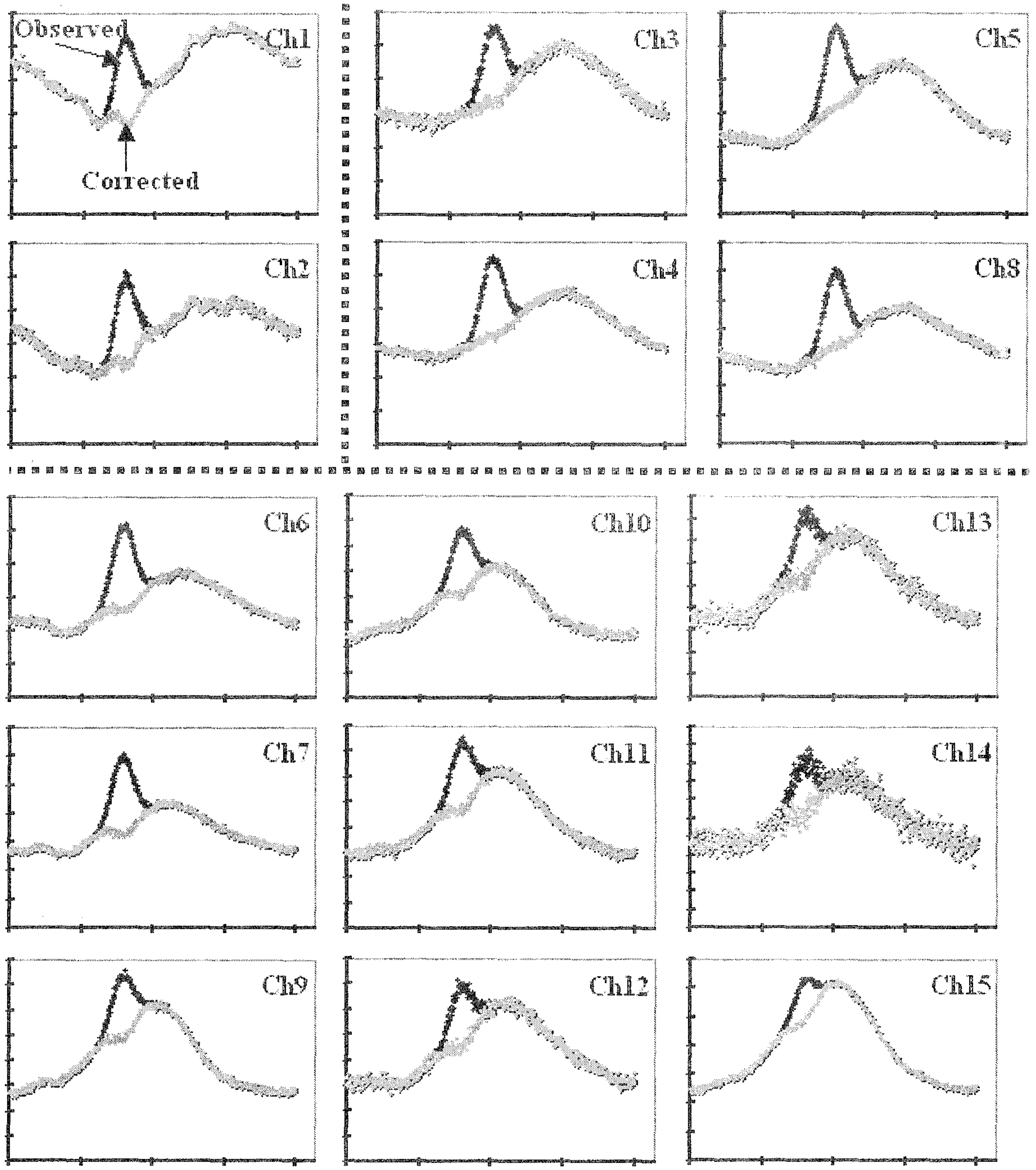

Figure 8. Space Counts Correction based on Pre-launch Antenna Pattern. [NOAA-16, 4/30/2001, 0523-0711UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

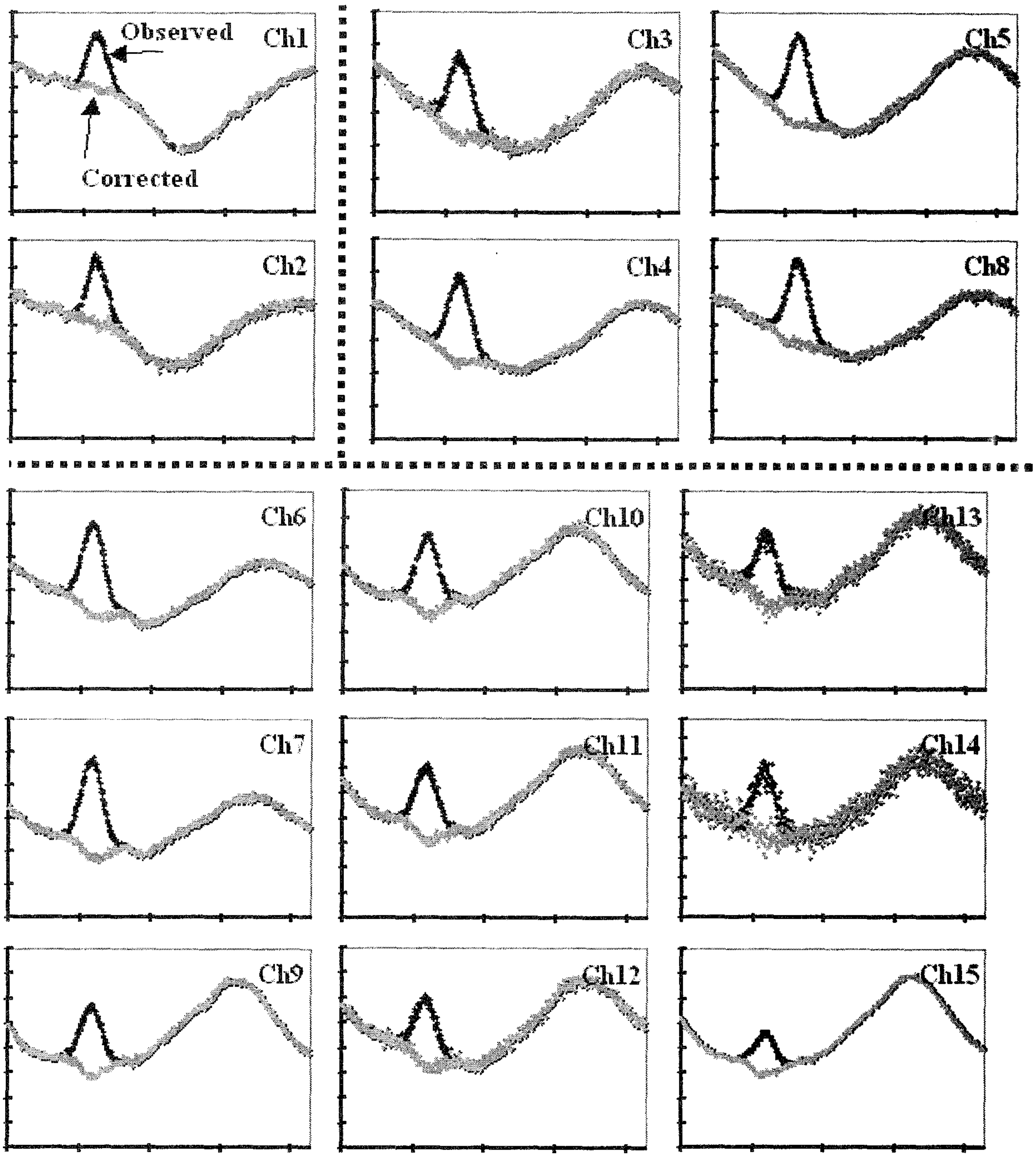

Figure 9. Space Counts Correction based on Pre-launch Antenna Pattern. [NOAA-16, 5/29/2001, 1830-2024UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

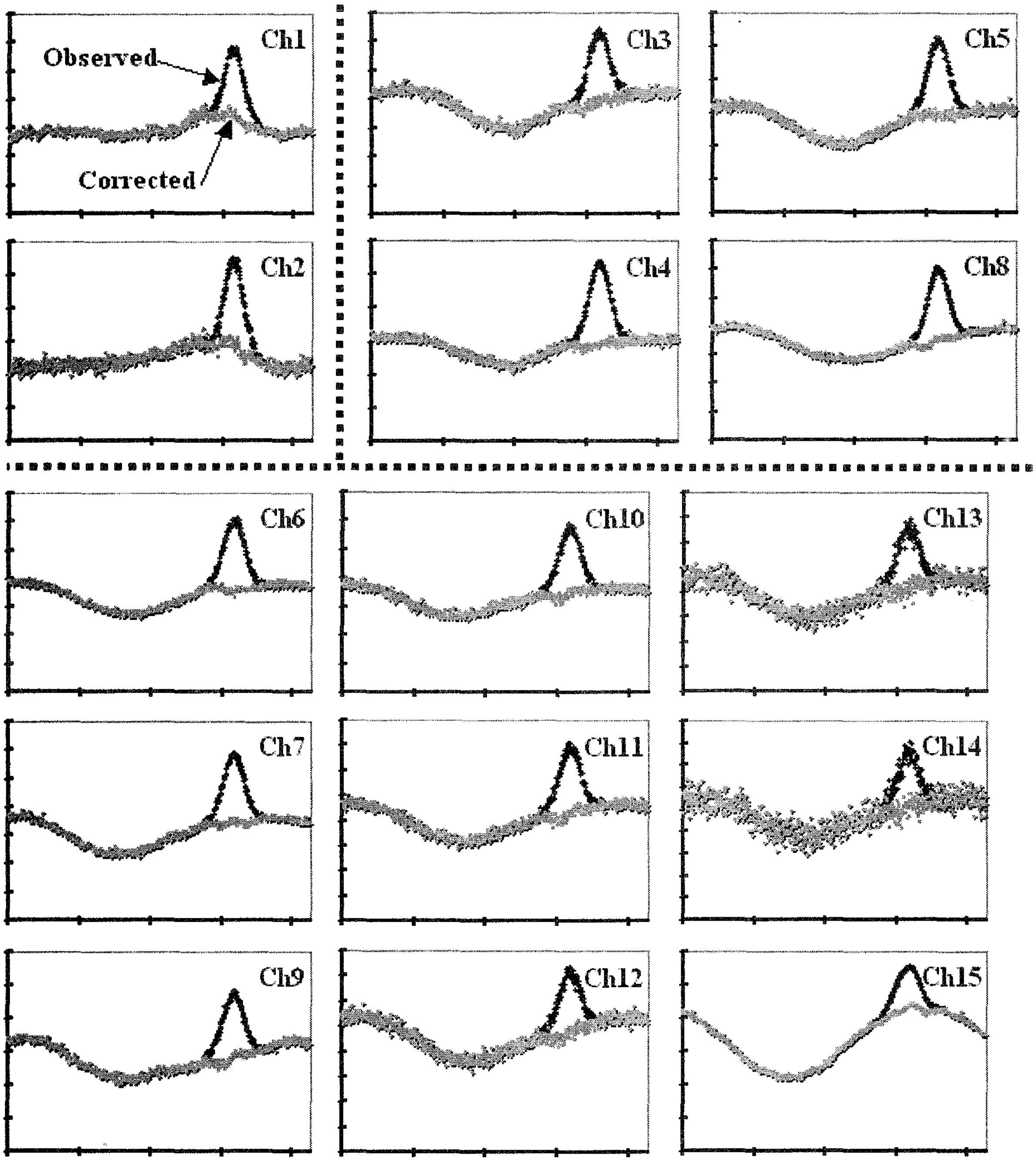

Figure 10. Space Counts Correction based on On-orbit Antenna Pattern.
[NOAA-15, 2/21/2000, 1320-1514UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

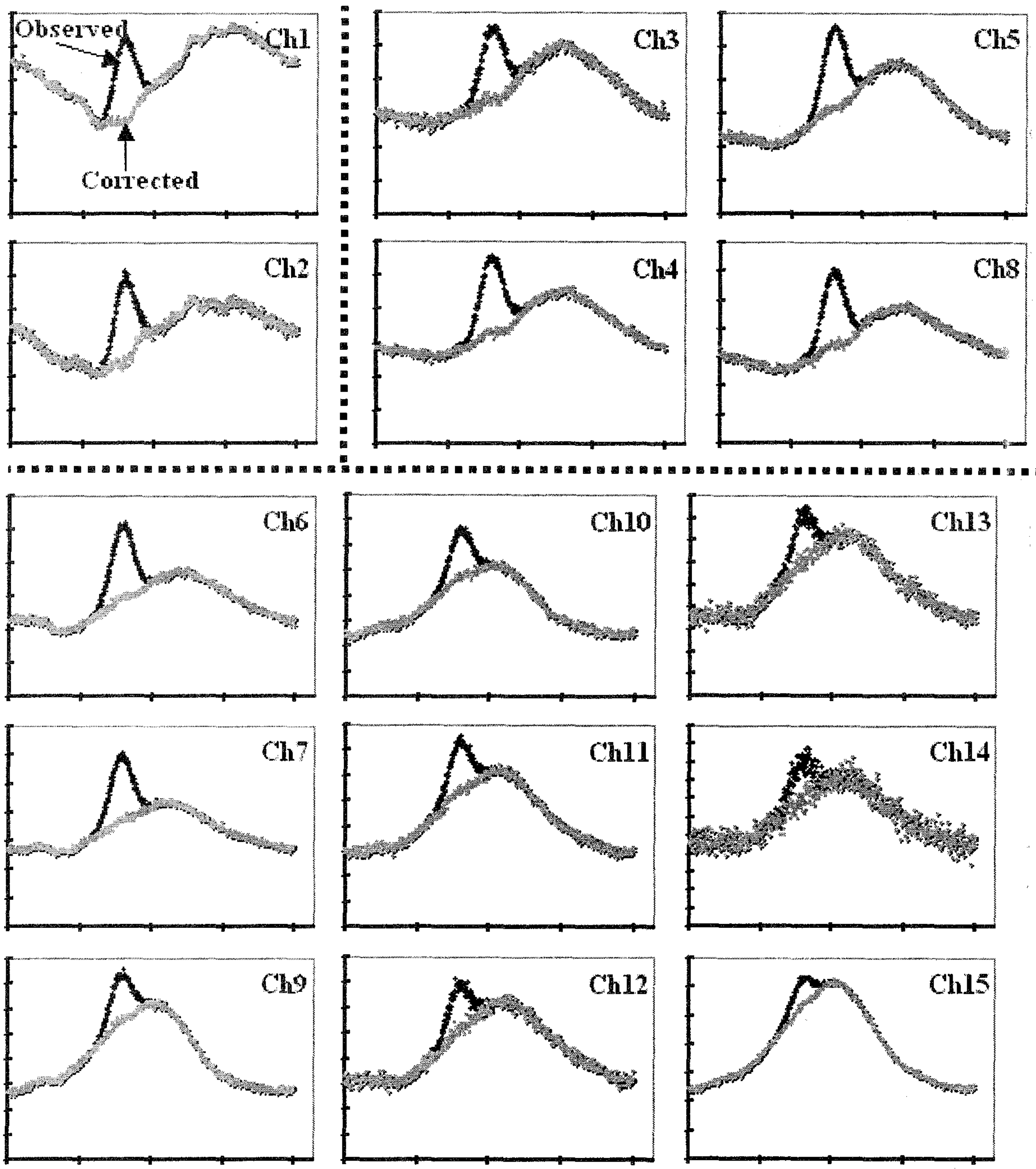

Figure 11. Space Counts Correction based on On-orbit Antenna Pattern. [NOAA-16, 4/30/2001, 0523-0711UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

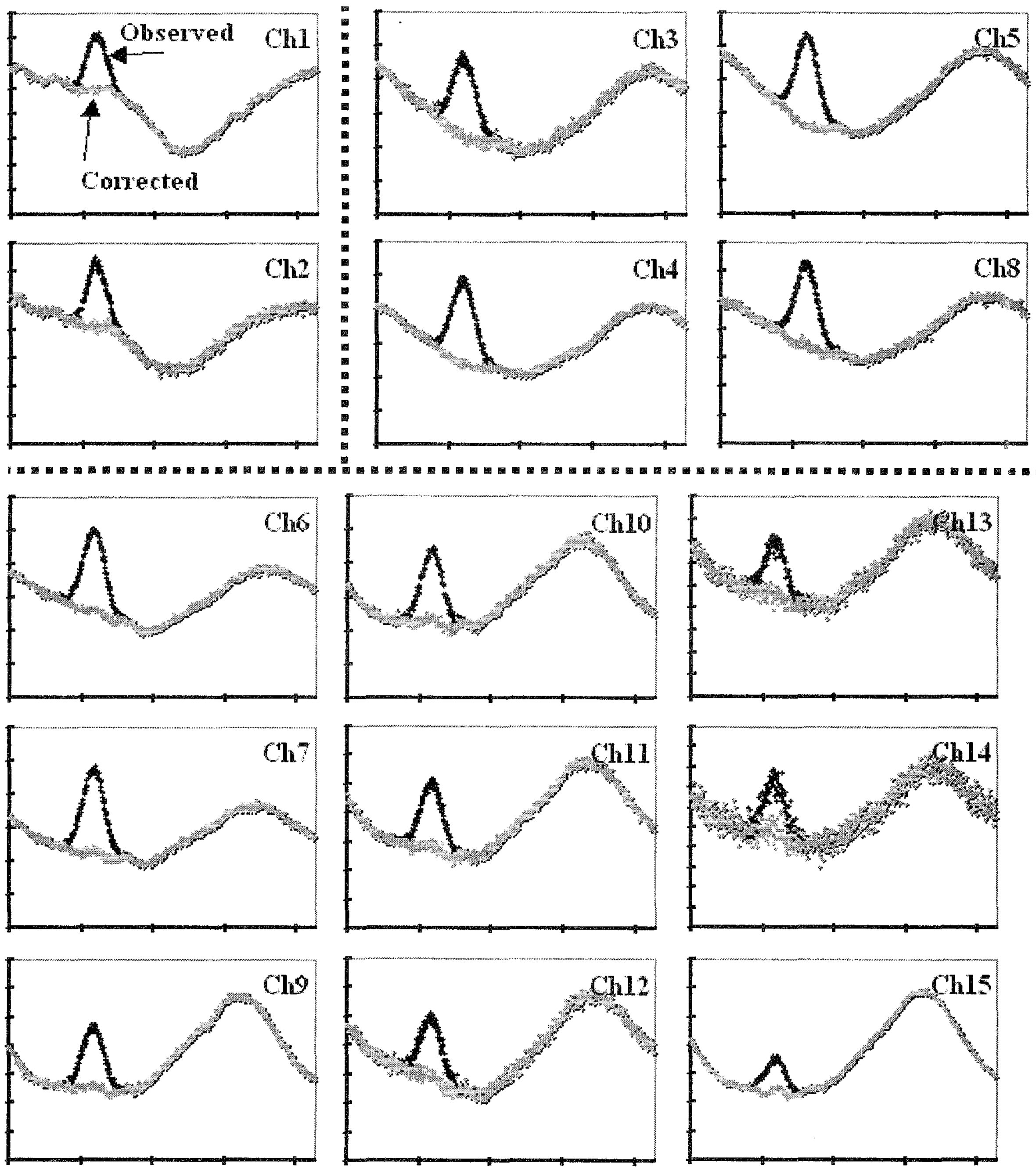

Figure 12. Space Counts Correction based on On-orbit Antenna Pattern.
[NOAA-16, 5/29/2001, 1830-2024UTC]

Vertical: Space Counts (20counts/div)

Horizontal: Scan Number (200scans/div)

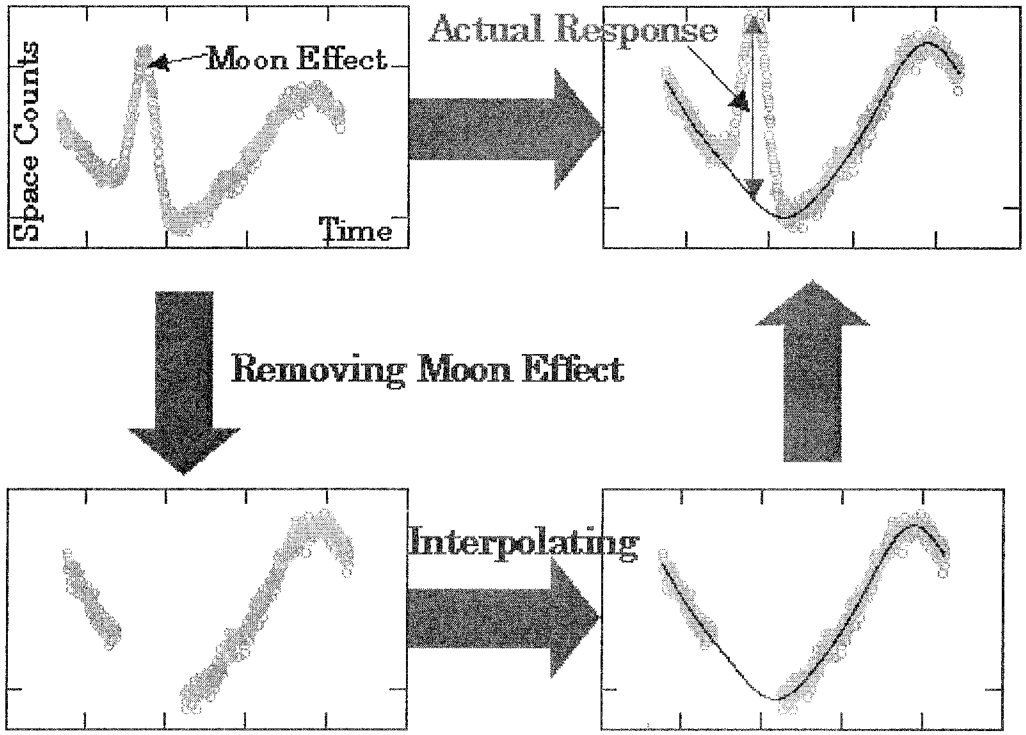

Figure 13. Concept of On-orbit Antenna Pattern Measurement.

APPENDIX A
Listing of Sample Software

The following is a sample program in Visual Basic that was used to produce the results as presented in this report.

```
DefDbl A-H, J-Z
Sub AMSU_Moon_Location()
'
'--- parameter definition ---
' PI
Pi = 3.14159265359
Rad = Pi / 180
' Earth shape parameters
Re = 6378.135
f = 1 / 298.25
ee = 2 * f - f * f
' Instrument parameters
Ti = 0.2025          'Duration between adjacent IFOVs (sec)
Ts = 8               'Time interval between adjacent scans (sec)
Pc = 15.5            'scan position of nadir
Sr = (3 + 1 / 3)     'scan angle interval between adjacent positions (degree)
S0 = Sr * Pc         'scan angle of position #0 (degree)
' others
Dim CM(3, 3) As Double
Dim EMT(3) As Double
Dim rc(15) As Double
Dim sigma_a(15) As Double, sigma_c(15) As Double
Dim theta_a(15) As Double, theta_c(15) As Double
Dim Total_scan As Integer, doff As Integer, P As Integer
Dim SheetA As String, SheetB As String, BookA As String
' Sheet Name
BookA = "L011512346"
SheetA = "L011512346"
SheetB = "NOAA16pre"
' SheetA MAP
'   column  row     info
'   2(B)    3-19999 scan_line
'   3(C)    3-19999 year
'   4(D)    3-19999 day (day + hour/24 + minuts/24/60 + sec/24/60/60)
'   5(E)    3-19999 lat15 [N deg]
'   6(F)    3-19999 lon15 [E deg]
'   7(G)    3-19999 lat16 [N deg]
'   8(H)    3-19999 lon16 [E deg]
'   9(I)    3-19999 lat30 [N deg]
'   10(J)   3-19999 lon30 [E deg]
'   11(K)   3-19999 cold position A-1 (0-3)
'   12(L)   3-19999 cold position A-2 (0-3)
'   13(M)   3-19999 A1-1 BB temp [K]
'   14(N)   3-19999 A1-2 BB temp [K]
'   15(O)   3-19999 A2 BB temp [K]
'   16(P)   3-19999 Ch1 observed BB counts
'   17(Q)   3-19999 Ch1 observed cold counts
'   18(R)   3-19999 Ch1 corrected cold counts
'   19(S)   3-19999 Ch2 observed BB counts
'   20(T)   3-19999 Ch2 observed cold counts
'   21(U)   3-19999 Ch2 corrected cold counts
'   ...
'   58(BF)  3-19999 Ch15 observed BB counts
'   59(BG)  3-19999 Ch15 observed cold counts
'   60(BH)  3-19999 Ch15 corrected cold counts
'
```

```
' Moon temperature coefficient
EMT(1) = 95.206
EMT(2) = 209.26
EMT(3) = 23.247
' Coefficient for Delta counts
For ich = 1 To 14
    If ich <= 9 Then
        rc(ich) = Sheets(SheetB).Cells(14 + ich, 6)
        sigma_a(ich) = Sheets(SheetB).Cells(14 + ich, 2)    'alpha s
        sigma_c(ich) = Sheets(SheetB).Cells(14 + ich, 3)    'delta s
        theta_a(ich) = Sheets(SheetB).Cells(14 + ich, 4)    'alpha 0
        theta_c(ich) = Sheets(SheetB).Cells(14 + ich, 5)    'delta 0
    Else
        rc(ich) = Sheets(SheetB).Cells(23, 6)
        sigma_a(ich) = Sheets(SheetB).Cells(23, 2)
        sigma_c(ich) = Sheets(SheetB).Cells(23, 3)
        theta_a(ich) = Sheets(SheetB).Cells(23, 4)
        theta_c(ich) = Sheets(SheetB).Cells(23, 5)
    End If
    rc(15) = Sheets(SheetB).Cells(24, 6)
    sigma_a(15) = Sheets(SheetB).Cells(24, 2)
    sigma_c(15) = Sheets(SheetB).Cells(24, 3)
    theta_a(15) = Sheets(SheetB).Cells(24, 4)
    theta_c(15) = Sheets(SheetB).Cells(24, 5)
Next ich
'
'--- input Earth location data ---
'    count total scans
For i = 1 To 19999
        If Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 2) = "" Then GoTo count_end
Next i
count_end:
Total_scan = i - 1
'
'--- correct earth location data ---
'
For i = 1 To Total_scan
        '~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
        ' Spacecraft position and attitude calculation
        '   Reference: AMSU-A Earth Location Improvement, S. Kigawa
        '~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~START~~~~
    '--- data input offset ---
    doff = 0
    If i = Total_scan Then doff = -1
    '--- scan n ---
    Lat15_1 = Workbooks(BookA).Sheets(SheetA).Cells(i + 2 + doff, 5) * Rad
    Lon15_1 = Workbooks(BookA).Sheets(SheetA).Cells(i + 2 + doff, 6) * Rad
    Lat16_1 = Workbooks(BookA).Sheets(SheetA).Cells(i + 2 + doff, 7) * Rad
    Lon16_1 = Workbooks(BookA).Sheets(SheetA).Cells(i + 2 + doff, 8) * Rad
    '--- vector 1 ---
    RN = Re / Sqr(1 - ee * Sin(CDbl(Lat15_1)) ^ 2)
    X1 = RN * Cos(CDbl(Lat15_1)) * Cos(CDbl(Lon15_1))
    Y1 = RN * Cos(CDbl(Lat15_1)) * Sin(CDbl(Lon15_1))
    Z1 = RN * (1 - ee) * Sin(CDbl(Lat15_1))
    ux1 = X1 / Sqr(X1 * X1 + Y1 * Y1 + Z1 * Z1)
    uy1 = Y1 / Sqr(X1 * X1 + Y1 * Y1 + Z1 * Z1)
    uz1 = Z1 / Sqr(X1 * X1 + Y1 * Y1 + Z1 * Z1)
    '--- vector 2 ---
    RN = Re / Sqr(1 - ee * Sin(CDbl(Lat16_1)) ^ 2)
    X2 = RN * Cos(CDbl(Lat16_1)) * Cos(CDbl(Lon16_1))
    Y2 = RN * Cos(CDbl(Lat16_1)) * Sin(CDbl(Lon16_1))
    Z2 = RN * (1 - ee) * Sin(CDbl(Lat16_1))
    ux2 = X2 / Sqr(X2 * X2 + Y2 * Y2 + Z2 * Z2)
    uy2 = Y2 / Sqr(X2 * X2 + Y2 * Y2 + Z2 * Z2)
    uz2 = Z2 / Sqr(X2 * X2 + Y2 * Y2 + Z2 * Z2)
    '--- vector 3 ---
    X3 = uy1 * uz2 - uz1 * uy2
```

```
Y3 = uz1 * ux2 - ux1 * uz2
Z3 = ux1 * uy2 - uy1 * ux2
ux3 = X3 / Sqr(X3 * X3 + Y3 * Y3 + Z3 * Z3)
uy3 = Y3 / Sqr(X3 * X3 + Y3 * Y3 + Z3 * Z3)
uz3 = Z3 / Sqr(X3 * X3 + Y3 * Y3 + Z3 * Z3)
'--- vector 4 ---
X4 = uy3 * uz1 - uz3 * uy1
Y4 = uz3 * ux1 - ux3 * uz1
Z4 = ux3 * uy1 - uy3 * ux1
ux4 = X4 / Sqr(X4 * X4 + Y4 * Y4 + Z4 * Z4)
uy4 = Y4 / Sqr(X4 * X4 + Y4 * Y4 + Z4 * Z4)
uz4 = Z4 / Sqr(X4 * X4 + Y4 * Y4 + Z4 * Z4)
'--- angle 1 to 2 ---
Call Arcos(CDbl(ux1 * ux2 + uy1 * uy2 + uz1 * uz2), angle12)
'--- vector 5 : nadir ---
ux5 = ux1 * CDbl(Cos(angle12 * CDbl(0.5))) + ux4 * CDbl(Sin(angle12 * CDbl(0.5)))
uy5 = uy1 * CDbl(Cos(angle12 * CDbl(0.5))) + uy4 * CDbl(Sin(angle12 * CDbl(0.5)))
uz5 = uz1 * CDbl(Cos(angle12 * CDbl(0.5))) + uz4 * CDbl(Sin(angle12 * CDbl(0.5)))

'--- scan n+1 ---
Lat15_2 = Workbooks(BookA).Sheets(SheetA).Cells(i + 3 + doff, 5) * Rad
Lon15_2 = Workbooks(BookA).Sheets(SheetA).Cells(i + 3 + doff, 6) * Rad
Lat16_2 = Workbooks(BookA).Sheets(SheetA).Cells(i + 3 + doff, 7) * Rad
Lon16_2 = Workbooks(BookA).Sheets(SheetA).Cells(i + 3 + doff, 8) * Rad
'--- vector 6 ---
RN = Re / Sqr(1 - ee * Sin(CDbl(Lat15_2)) ^ 2)
X6 = RN * Cos(CDbl(Lat15_2)) * Cos(CDbl(Lon15_2))
Y6 = RN * Cos(CDbl(Lat15_2)) * Sin(CDbl(Lon15_2))
Z6 = RN * (1 - ee) * Sin(CDbl(Lat15_2))
ux6 = X6 / Sqr(X6 * X6 + Y6 * Y6 + Z6 * Z6)
uy6 = Y6 / Sqr(X6 * X6 + Y6 * Y6 + Z6 * Z6)
uz6 = Z6 / Sqr(X6 * X6 + Y6 * Y6 + Z6 * Z6)
'--- vector 7 ---
RN = Re / Sqr(1 - ee * Sin(CDbl(Lat16_2)) ^ 2)
X7 = RN * Cos(CDbl(Lat16_2)) * Cos(CDbl(Lon16_2))
Y7 = RN * Cos(CDbl(Lat16_2)) * Sin(CDbl(Lon16_2))
Z7 = RN * (1 - ee) * Sin(CDbl(Lat16_2))
ux7 = X7 / Sqr(X7 * X7 + Y7 * Y7 + Z7 * Z7)
uy7 = Y7 / Sqr(X7 * X7 + Y7 * Y7 + Z7 * Z7)
uz7 = Z7 / Sqr(X7 * X7 + Y7 * Y7 + Z7 * Z7)
'--- vector 8 ---
X8 = uy6 * uz7 - uz6 * uy7
Y8 = uz6 * ux7 - ux6 * uz7
Z8 = ux6 * uy7 - uy6 * ux7
ux8 = X8 / Sqr(X8 * X8 + Y8 * Y8 + Z8 * Z8)
uy8 = Y8 / Sqr(X8 * X8 + Y8 * Y8 + Z8 * Z8)
uz8 = Z8 / Sqr(X8 * X8 + Y8 * Y8 + Z8 * Z8)
'--- vector 9 ---
X9 = uy8 * uz6 - uz8 * uy6
Y9 = uz8 * ux6 - ux8 * uz6
Z9 = ux8 * uy6 - uy8 * ux6
ux9 = X9 / Sqr(X9 * X9 + Y9 * Y9 + Z9 * Z9)
uy9 = Y9 / Sqr(X9 * X9 + Y9 * Y9 + Z9 * Z9)
uz9 = Z9 / Sqr(X9 * X9 + Y9 * Y9 + Z9 * Z9)
'--- angle 6 to 7 ---
Call Arcos(CDbl(ux6 * ux7 + uy6 * uy7 + uz6 * uz7), angle67)
'--- vector 10 : nadir ---
ux10 = ux6 * CDbl(Cos(angle67 * CDbl(0.5))) + ux9 * CDbl(Sin(angle67 * CDbl(0.5)))
uy10 = uy6 * CDbl(Cos(angle67 * CDbl(0.5))) + uy9 * CDbl(Sin(angle67 * CDbl(0.5)))
uz10 = uz6 * CDbl(Cos(angle67 * CDbl(0.5))) + uz9 * CDbl(Sin(angle67 * CDbl(0.5)))
'--- vector 11 ---
X11 = uy5 * uz10 - uz5 * uy10
Y11 = uz5 * ux10 - ux5 * uz10
Z11 = ux5 * uy10 - uy5 * ux10
ux11 = X11 / Sqr(X11 * X11 + Y11 * Y11 + Z11 * Z11)
uy11 = Y11 / Sqr(X11 * X11 + Y11 * Y11 + Z11 * Z11)
uz11 = Z11 / Sqr(X11 * X11 + Y11 * Y11 + Z11 * Z11)
```

```
'--- vector 12 ---
X12 = uy11 * uz5 - uz11 * uy5
Y12 = uz11 * ux5 - ux11 * uz5
Z12 = ux11 * uy5 - uy11 * ux5
ux12 = X12 / Sqr(X12 * X12 + Y12 * Y12 + Z12 * Z12)
uy12 = Y12 / Sqr(X12 * X12 + Y12 * Y12 + Z12 * Z12)
uz12 = Z12 / Sqr(X12 * X12 + Y12 * Y12 + Z12 * Z12)
'--- angle 5 to 10 ---
Call Arcos(CDbl(ux5 * ux10 + uy5 * uy10 + uz5 * uz10), angle510)
'--- correction for each position ---
P = 30
'--- nadir ---
ratio = CDbl(P - Pc) * Ti / Ts + CDbl(-doff)
uxN = ux5 * CDbl(Cos(angle510 * ratio)) + ux12 * CDbl(Sin(angle510 * ratio))
uyN = uy5 * CDbl(Cos(angle510 * ratio)) + uy12 * CDbl(Sin(angle510 * ratio))
uzN = uz5 * CDbl(Cos(angle510 * ratio)) + uz12 * CDbl(Sin(angle510 * ratio))
'--- yaw (+Xp) vector ---
uxyaw = -uxN
uyyaw = -uyN
uzyaw = -uzN
'--- scene vector ---
scan = (-Sr * CDbl(P) + S0) * Rad
Latp = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 9) * Rad
Lonp = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 10) * Rad
RN = Re / Sqr(1 - ee * Sin(CDbl(Latp)) ^ 2)
Xp = RN * Cos(CDbl(Latp)) * Cos(CDbl(Lonp))
Yp = RN * Cos(CDbl(Latp)) * Sin(CDbl(Lonp))
Zp = RN * (1 - ee) * Sin(CDbl(Latp))
uxp = Xp / Sqr(Xp * Xp + Yp * Yp + Zp * Zp)
uyp = Yp / Sqr(Xp * Xp + Yp * Yp + Zp * Zp)
uzp = Zp / Sqr(Xp * Xp + Yp * Yp + Zp * Zp)
'--- roll (+Yp) vector ---
Xroll = (uyyaw * uzp - uzyaw * uyp) * -Sgn(scan)
Yroll = (uzyaw * uxp - uxyaw * uzp) * -Sgn(scan)
Zroll = (uxyaw * uyp - uyyaw * uxp) * -Sgn(scan)
uxroll = Xroll / Sqr(Xroll * Xroll + Yroll * Yroll + Zroll * Zroll)
uyroll = Yroll / Sqr(Xroll * Xroll + Yroll * Yroll + Zroll * Zroll)
uzroll = Zroll / Sqr(Xroll * Xroll + Yroll * Yroll + Zroll * Zroll)
'--- pitch (+Zp) vector ---
uxpitch = uyyaw * uzroll - uzyaw * uyroll
uypitch = uzyaw * uxroll - uxyaw * uzroll
uzpitch = uxyaw * uyroll - uyyaw * uxroll
'--- satellite point ---
Call Arcos((uxN * uxp + uyN * uyp + uzN * uzp), angleNp)
Xo = CDbl(Sin(angleNp)/Tan(Abs(scan))+Cos(angleNp))*Sqr(Xp*Xp+Yp*Yp+Zp*Zp)*uxN
Yo = CDbl(Sin(angleNp)/Tan(Abs(scan))+Cos(angleNp))*Sqr(Xp*Xp+Yp*Yp+Zp*Zp)*uyN
Zo = CDbl(Sin(angleNp)/Tan(Abs(scan))+Cos(angleNp))*Sqr(Xp*Xp+Yp*Yp+Zp*Zp)*uzN
altitude = Sqr(Xo * Xo + Yo * Yo + Zo * Zo) - Re
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~END~~~~~~
iyear% = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 3)
iday! = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 4)
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
' Moon position calculation
'   Reference: Moon position to 4arcmin by Keith Burnett
'              http://www.btinternet.com/~kburnett/kepler/moon2.html
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~START~~~~
'--- time conversion ---
DaystoJ2000 = DateSerial(iyear%, 1, 1) + (iday! - 1) - (DateSerial(2000, 1, 1) + 0.5)
d = DateSerial(iyear%, 1, 1) + (iday! - 1) - DateSerial(1999, 12, 31)
If (i) Mod (8) = 1 Then
    '--- moon elements ---
    Nm = FNrange((125.1228 - 0.0529538083 * d) * Rad)
    im = 5.1454 * Rad
    wm = FNrange((318.0634 + 0.1643573223 * d) * Rad)
    am = 60.2666  '(Earth radii)
    ecm = 0.0549
    Mm = FNrange((115.3654 + 13.0649929509 * d) * Rad)
```

```
'--- sun elements ---
Ns = 0
isun = 0
ws = FNrange((282.9404 + 0.0000470935 * d) * Rad)
asun = 1        '(AU)
ecs = 0.016709 - 0.000000001151 * d
Ms = FNrange((356.047 + 0.9856002585 * d) * Rad)
'--- position of Moon ---
Em = Mm + ecm * Sin(Mm) * (1 + ecm * Cos(Mm))
xv = am * (Cos(Em) - ecm)
yv = am * (Sqr(1 - ecm * ecm) * Sin(Em))
vm = FNatn2(yv, xv)
rm = Sqr(xv * xv + yv * yv)
xh = rm * (Cos(Nm) * Cos(vm + wm) - Sin(Nm) * Sin(vm + wm) * Cos(im))
yh = rm * (Sin(Nm) * Cos(vm + wm) + Cos(Nm) * Sin(vm + wm) * Cos(im))
zh = rm * (Sin(vm + wm) * Sin(im))
'--- lunar geocentric long and lat ---
Lon = FNatn2(yh, xh)
Lat = FNatn2(zh, Sqr(xh * xh + yh * yh))
'--- perturbations ---
Ls = Ms + ws                'Mean Longitude of the Sun  (Ns=0)
Lm = Mm + wm + Nm           'Mean longitude of the Moon
dm = Lm - Ls                'Mean elongation of the Moon
f = Lm - Nm                 'Argument of latitude for the Moon
dlon = -1.274 * Sin(Mm - 2 * dm)        '(the Evection)
dlon = dlon + 0.658 * Sin(2 * dm)       '(the Variation)
dlon = dlon - 0.186 * Sin(Ms)           '(the Yearly Equation)
dlon = dlon - 0.059 * Sin(2 * Mm - 2 * dm)
dlon = dlon - 0.057 * Sin(Mm - 2 * dm + Ms)
dlon = dlon + 0.053 * Sin(Mm + 2 * dm)
dlon = dlon + 0.046 * Sin(2 * dm - Ms)
dlon = dlon + 0.041 * Sin(Mm - Ms)
dlon = dlon - 0.035 * Sin(dm)           '(the Parallactic Equation)
dlon = dlon - 0.031 * Sin(Mm + Ms)
dlon = dlon - 0.015 * Sin(2 * f - 2 * dm)
dlon = dlon + 0.011 * Sin(Mm - 4 * dm)
Lon = dlon * Rad + Lon
'--- latitude terms ---
dlat = -0.173 * Sin(f - 2 * dm)
dlat = dlat - 0.055 * Sin(Mm - f - 2 * dm)
dlat = dlat - 0.046 * Sin(Mm + f - 2 * dm)
dlat = dlat + 0.033 * Sin(f + 2 * dm)
dlat = dlat + 0.017 * Sin(2 * Mm + f)
Lat = dlat * Rad + Lat
'--- distance terms earth radii ---
rm = rm - 0.58 * Cos(Mm - 2 * dm)
rm = rm - 0.46 * Cos(2 * dm)
'--- geocentric lunar position ---
xg = rm * Cos(Lon) * Cos(Lat)
yg = rm * Sin(Lon) * Cos(Lat)
zg = rm * Sin(Lat)
'--- rotating to equatorial coordinates ---
ecl = (23.4393 - 0.0000003563 * d) * Rad
Xe = xg
Ye = (yg * Cos(ecl) - zg * Sin(ecl))
Ze = (yg * Sin(ecl) + zg * Cos(ecl))
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~END~~~~~~
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
' AMSU-A Cold Calibration Correction
'   Reference: AMSU-A Cold Calibration Improvement, S.Kigawa
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~START~~~~
'--- sun pointing vector ---
MJD = DaystoJ2000 + 51544.5
Mwork = 315.253 + 0.98560027 * MJD
Lwork = 237.039 + 0.9856091 * MJD + 1.916 * Sin(Mwork*Rad)+0.02*Sin(2*Mwork*Rad)
Rwork = 1.00014 - 0.01672 * Cos(Mwork * Rad) - 0.00014 * Cos(2 * Mwork * Rad)
Xsun = Rwork * Cos(Lwork * Rad)
```

```
        Ysun = 0.9174 * Rwork * Sin(Lwork * Rad)
        Zsun = 0.3979 * Rwork * Sin(Lwork * Rad)
        uXsun = Xsun / Sqr(Xsun * Xsun + Ysun * Ysun + Zsun * Zsun)
        uYsun = Ysun / Sqr(Xsun * Xsun + Ysun * Ysun + Zsun * Zsun)
        uZsun = Zsun / Sqr(Xsun * Xsun + Ysun * Ysun + Zsun * Zsun)
        '--- moon-sun apart angle ---
        uXmoon = Xe / Sqr(Xe * Xe + Ye * Ye + Ze * Ze)
        uYmoon = Ye / Sqr(Xe * Xe + Ye * Ye + Ze * Ze)
        uZmoon = Ze / Sqr(Xe * Xe + Ye * Ye + Ze * Ze)
        cosmoonsun = uXsun * uXmoon + uYsun * uYmoon + uZsun * uZmoon
        Call Arcos(cosmoonsun, anglemoonsun)
        '--- Moon temperature ---
        EffectiveMoonTemp = EMT(1) + (Cos(Pi - anglemoonsun) + 1) * 0.5 * EMT(2)
        EffectiveMoonTemp = EffectiveMoonTemp +(Cos(2 * (Pi - anglemoonsun)) + 1)*0.5*EMT(3)
    End If
    '--- local siderial time ---
    lst = (100.46 + 0.985647352 * DaystoJ2000 + CDbl(iday! - Int(iday!)) * 24 * 15)*Rad
    lst = FNrange(lst)
    '--- moon pointing vector ---
    Xmoon = (Xe * Cos(lst) + Ye * Sin(lst)) - Xo / Re
    Ymoon = (Xe * -Sin(lst) + Ye * Cos(lst)) - Yo / Re
    Zmoon = Ze - Zo / Re
    De = Sqr(Xmoon * Xmoon + Ymoon * Ymoon + Zmoon * Zmoon)
    rradius = am / De
    '--- ch1 to ch15 ---
    For ich = 1 To 15
        '--- input ---
        If ich < 3 Then coldposition = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 12)
        If ich >= 3 Then coldposition = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 11)
        If ich < 3 Then
            BBtemp = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 15)
        Else
            If ich = 3 Or ich = 4 Or ich = 5 Or ich = 8 Then
                BBtemp = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 14)
            Else
                BBtemp = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 13)
            End If
        End If
        BBcounts = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 16 + (ich - 1) * 3)
        coldcounts = Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 17 + (ich - 1) * 3)
'--- cold cal postion ---
        If coldposition = 0 Then coldscan = -(90 - 6.667) * Rad
        If coldposition = 1 Then coldscan = -(90 - 8.333) * Rad
        If coldposition = 2 Then coldscan = -(90 - 9.999) * Rad
        If coldposition = 3 Then coldscan = -(90 - 13.332) * Rad
        '--- pointing vector ---
        dRoll = 0
        dPitch = 0
        dYaw = 0
        dR = CDbl(dRoll)
        dP = CDbl(dPitch)
        dY = CDbl(dYaw)
        CM(1, 1) = CDbl(Cos(dP) * Cos(dR))
        CM(1, 2) = CDbl(Cos(dP) * Sin(dR) * Sin(dY) - Sin(dP) * Cos(dY))
        CM(1, 3) = CDbl(Cos(dP) * Sin(dR) * Cos(dY) + Sin(dP) * Sin(dY))
        CM(2, 1) = CDbl(Sin(dP) * Cos(dR))
        CM(2, 2) = CDbl(Sin(dP) * Sin(dR) * Sin(dY) + Cos(dP) * Cos(dY))
        CM(2, 3) = CDbl(Sin(dP) * Sin(dR) * Cos(dY) - Cos(dP) * Sin(dY))
        CM(3, 1) = CDbl(-Sin(dR))
        CM(3, 2) = CDbl(Cos(dR) * Sin(dY))
        CM(3, 3) = CDbl(Cos(dR) * Cos(dY))
        uxcpp = CM(1, 1) * CDbl(Cos(coldscan)) + CM(1, 3) * CDbl(Sin(coldscan))
        uycpp = CM(2, 1) * CDbl(Cos(coldscan)) + CM(2, 3) * CDbl(Sin(coldscan))
        uzcpp = CM(3, 1) * CDbl(Cos(coldscan)) + CM(3, 3) * CDbl(Sin(coldscan))
        uxcp = uxyaw * uxcpp + uxroll * uycpp + uxpitch * uzcpp
        uycp = uyyaw * uxcpp + uyroll * uycpp + uypitch * uzcpp
        uzcp = uzyaw * uxcpp + uzroll * uycpp + uzpitch * uzcpp
```

```
        '--- Angle between moon and cold cal position ---
        cosmoon = (uxcp * Xmoon + uycp * Ymoon + uzcp * Zmoon) / De
        Call Arcos(cosmoon, anglemoon)
        '--- Moon Azimuth and Elevation ---
        ua1 = uxcp
        ua2 = uycp
        ua3 = uzcp
        ud1 = Xmoon / De
        ud2 = Ymoon / De
        ud3 = Zmoon / De
        uc1 = -uxroll
        uc2 = -uyroll
        uc3 = -uzroll
        ub1 = uc2 * ua3 - ua2 * uc3
        ub2 = uc3 * ua1 - ua3 * uc1
        ub3 = uc1 * ua2 - ua1 * uc2
        ubd = Sqr(ub1 * ub1 + ub2 * ub2 + ub3 * ub3)
        ub1 = ub1 / ubd
        ub2 = ub2 / ubd
        ub3 = ub3 / ubd
        D0 = ua1*ub2*uc3 +ub1*uc2*ua3 +uc1*ua2*ub3 -ua1*uc2*ub3 -ub1*ua2*uc3 -uc1*ub2*ua3
        D1 = ud1*ub2*uc3 +ub1*uc2*ud3 +uc1*ud2*ub3 -ud1*uc2*ub3 -ub1*ud2*uc3 -uc1*ub2*ud3
        D2 = ua1*ud2*uc3 +ud1*uc2*ua3 +uc1*ua2*ud3 -ua1*uc2*ud3 -ud1*ua2*uc3 -uc1*ud2*ua3
        D3 = ua1*ub2*ud3 +ub1*ud2*ua3 +ud1*ua2*ub3 -ua1*ud2*ub3 -ub1*ua2*ud3 -ud1*ub2*ua3
        If D0 <> 0 Then
            If D1 <> 0 And D3 <> 0 Then
                ELcc = Atn(D2 / D0 / Sqr((D1 * D1 + D3 * D3) / (D0 * D0)))
            Else
                ELcc = 0
            End If
            If D1 <> 0 Then
                AZcc = Atn(D3 / D1)
                If D1 < 0 And D3 >= 0 Then AZcc = AZcc + Pi
                If D1 < 0 And D3 < 0 Then AZcc = AZcc - Pi
            Else
                If D3 > 0 Then
                    AZcc = Pi / 2
                Else
                    AZcc = -Pi / 2
                End If
            End If
        Else
            AZcc = 0
            ELcc = 0
        End If
        AZcc = -AZcc
        ELcc = -ELcc
        '--- Corrected Cold Counts ---
        pmoon_a = Exp(-(AZcc / Rad - theta_a(ich)) ^ 2 / (2*sigma_a(ich) ^ 2))*Sqr(rc(ich))
        pmoon_c = Exp(-(ELcc / Rad - theta_c(ich)) ^ 2 / (2*sigma_c(ich) ^ 2))*Sqr(rc(ich))
        pmoon = pmoon_a * pmoon_c
        deltaT = pmoon * EffectiveMoonTemp * (rradius ^ 2)
        ccc = ((BBtemp - 2.73) * coldcounts - deltaT * BBcounts) / (BBtemp - 2.73 - deltaT)
        '~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~END~~~~~~
        '--- print ---
        Workbooks(BookA).Sheets(SheetA).Cells(i + 2, 18 + (ich - 1) * 3) = ccc
'
    Next ich
'
Next i
'
End Sub
Sub Arcos(cosine As Double, angle)
Dim Pi As Double
Pi = 3.14159265359
If cosine <> 0 Then
    If cosine > 0 Then
```

```
        angle = CDbl(Atn(Sqr(1 / cosine ^ 2 - 1)))
    Else
        angle = Pi - CDbl(Atn(Sqr(1 / cosine ^ 2 - 1)))
    End If
Else
    angle = CDbl(0)
End If
End Sub
Function FNrange(x As Double) As Double
    Dim Pi As Double
    Pi = 3.14159265359
    FNrange = x - Int(x / 2# / Pi) * 2# * Pi
End Function
Function FNatn2(y As Double, x As Double)
    Dim Pi As Double, a As Double
    Pi = 3.14159265359
    a = Atn(y / x)
    If x < 0 Then a = a + Pi
    If (y < 0) And (x > 0) Then a = a + Pi * 2
    FNatn2 = a
End Function
```

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